

# Lignin-Based Carbon Materials

- Potential High Value and High Volume Applications

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*100 Years of Service*



**Forest Products  
Laboratory**

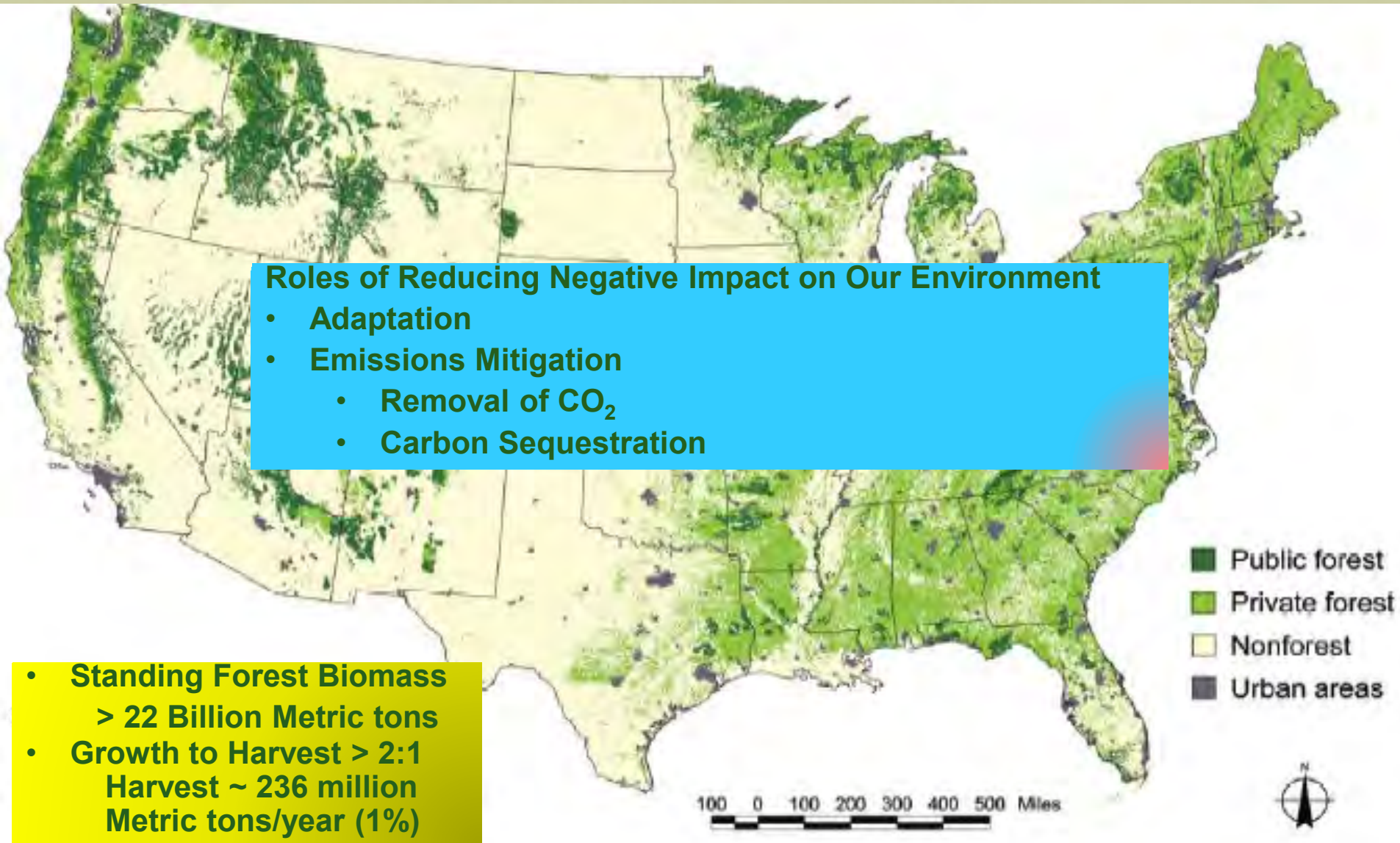
*1910-2010*





# America's Forest Resource

749 Million Acres





# Forest Products Laboratory

## Mission

Identify and conduct innovative wood and fiber utilization research that contributes to conservation and productivity of the forest resource, thereby sustaining forests, the economy, and quality of life.





# Oldest Prefabricated Wood Structure in USA



# FPL Research Focus Areas



- Advanced composites
- Advanced structures
- Nanotechnology
- Biorefinery/bioenergy
- Forest Management (Products as tools)



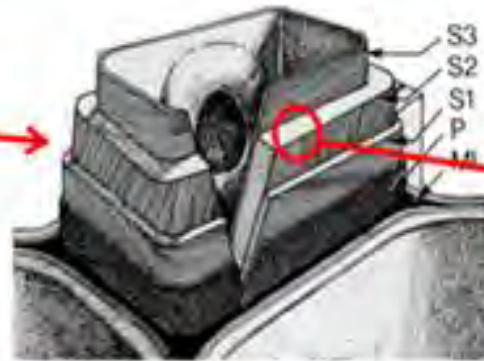
Forest products, biomass



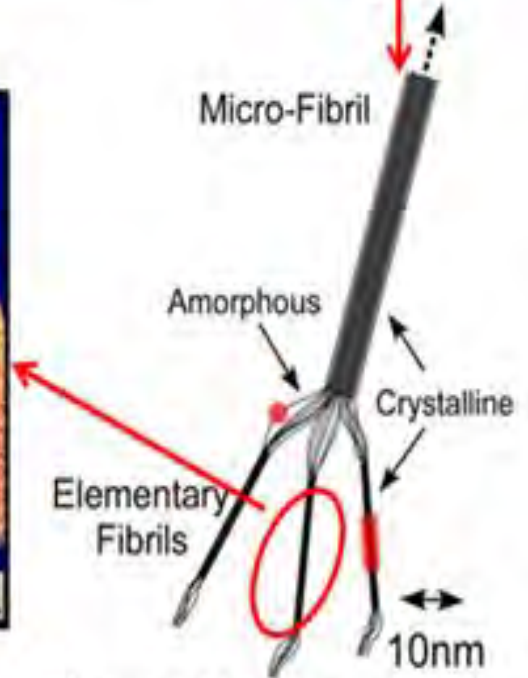
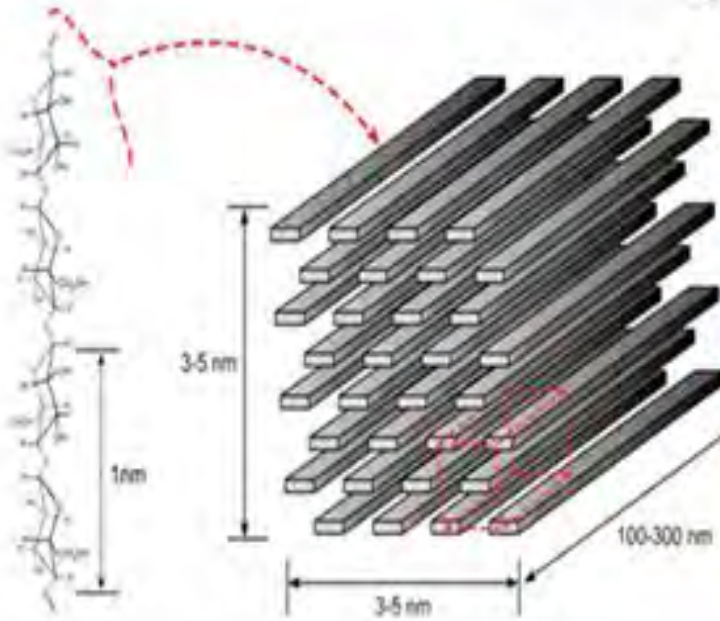
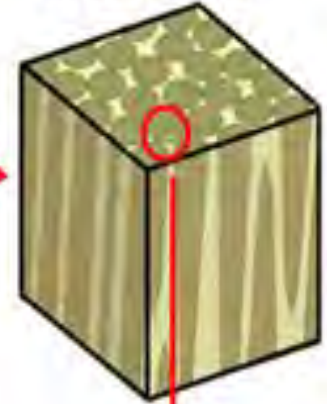
Wood cells



Cell wall layers



Cellulose microfibrils  
In cell walls

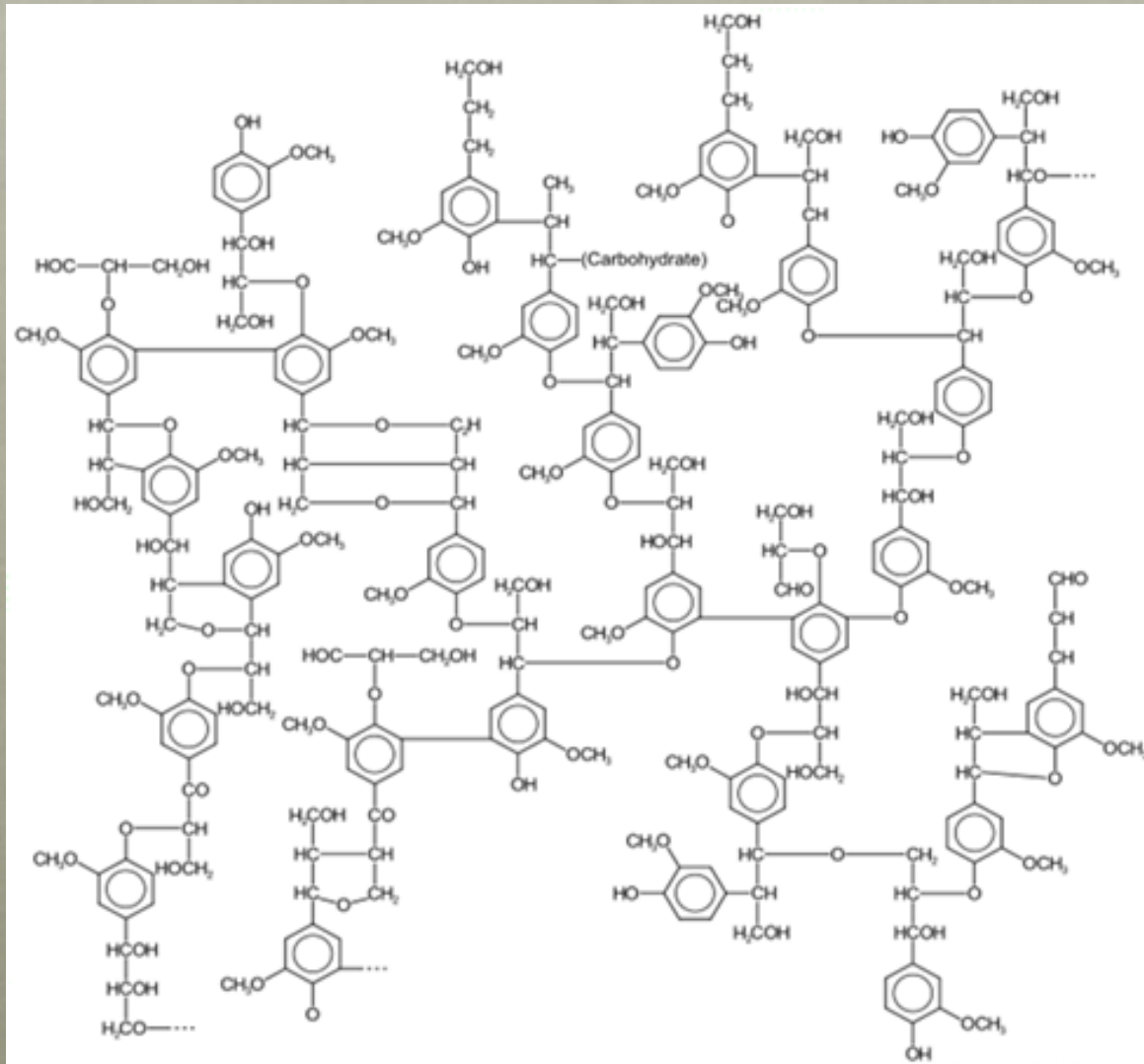


CNC's consist of organized stacks of  $I_{\alpha}$ ,  $I_{\beta}$  cellulose chains

AFM image of a cellulose Nanocrystal (CNC)

Chemical treatment releases crystalline phase

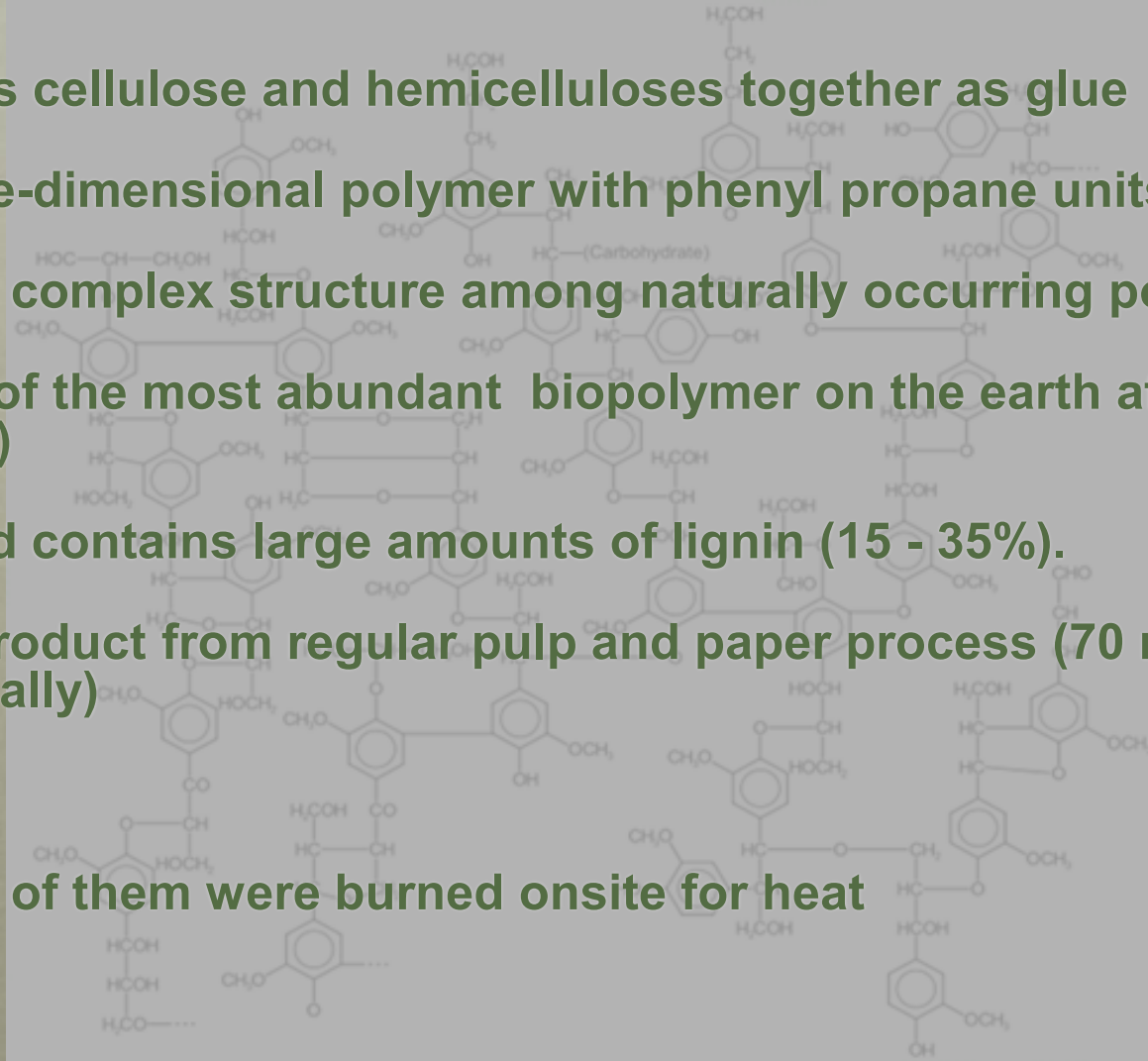
# What is lignin?





# What is lignin?

- Holds cellulose and hemicelluloses together as glue
- Three-dimensional polymer with phenyl propane units.
- Most complex structure among naturally occurring polymers.
- One of the most abundant biopolymer on the earth after cellulose (30%)
- Wood contains large amounts of lignin (15 - 35%).
- By-product from regular pulp and paper process (70 millions tons annually)
- Most of them were burned onsite for heat



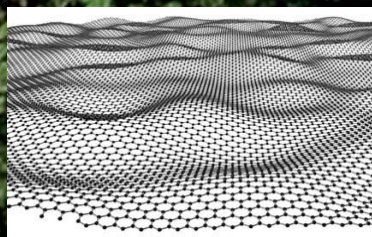


# FPL Lignin Projects

- Lignin-based graphene
  - US 9,540,244 B2 and US 10,669,155 B2
- Lignin-based foam
  - US Pat Appl No. 16/391,424 2019
- Lignin-based carbon foam
  - US Pat Appl No 15/896,265 2018
- Activated carbon

To develop a commercial manufacturing mode and high-volume production of valuable carbonaceous materials from a bio-waste lignin.

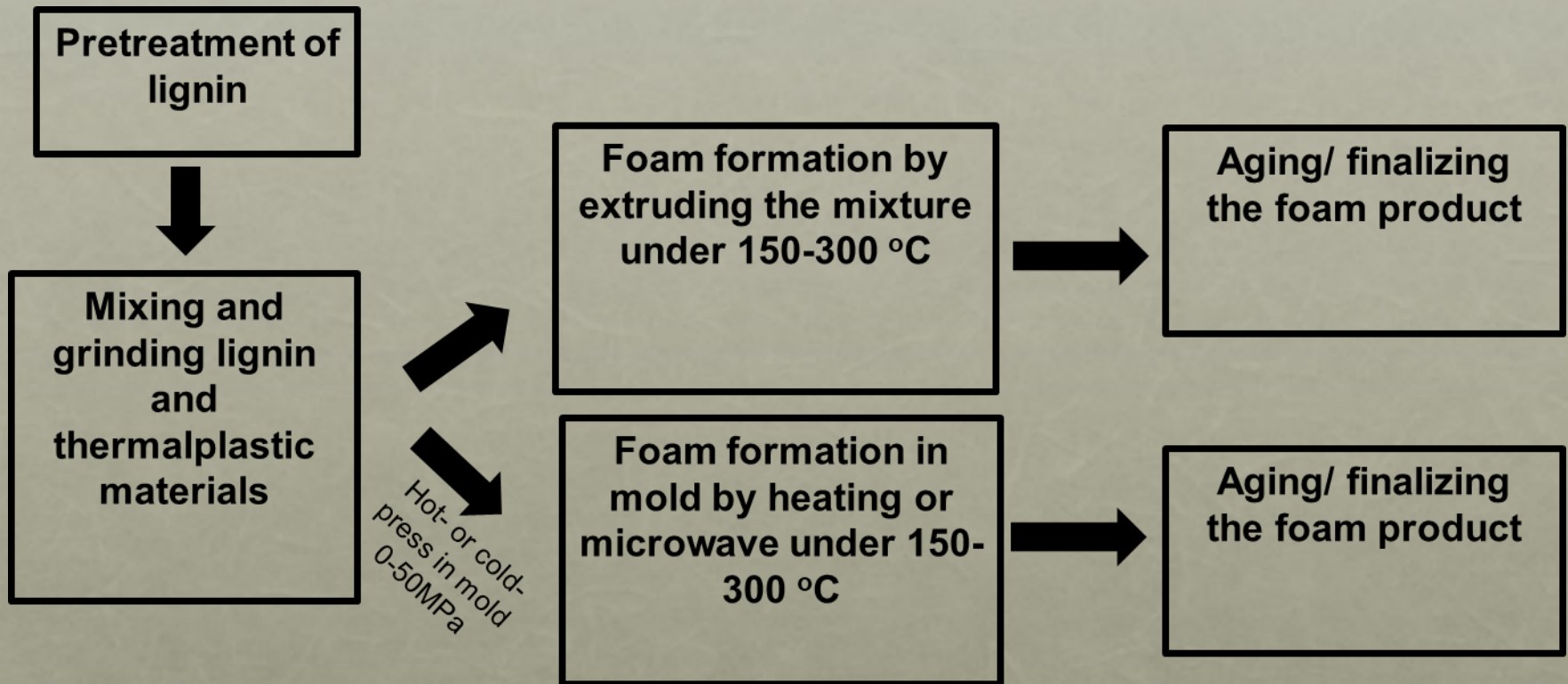




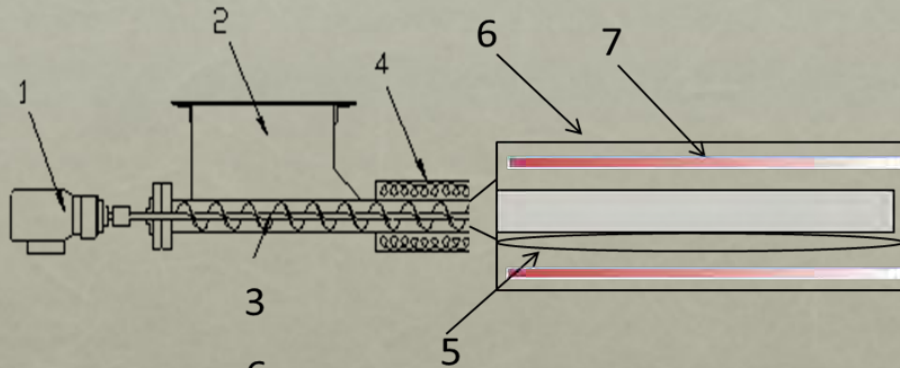
# Lignin Foam



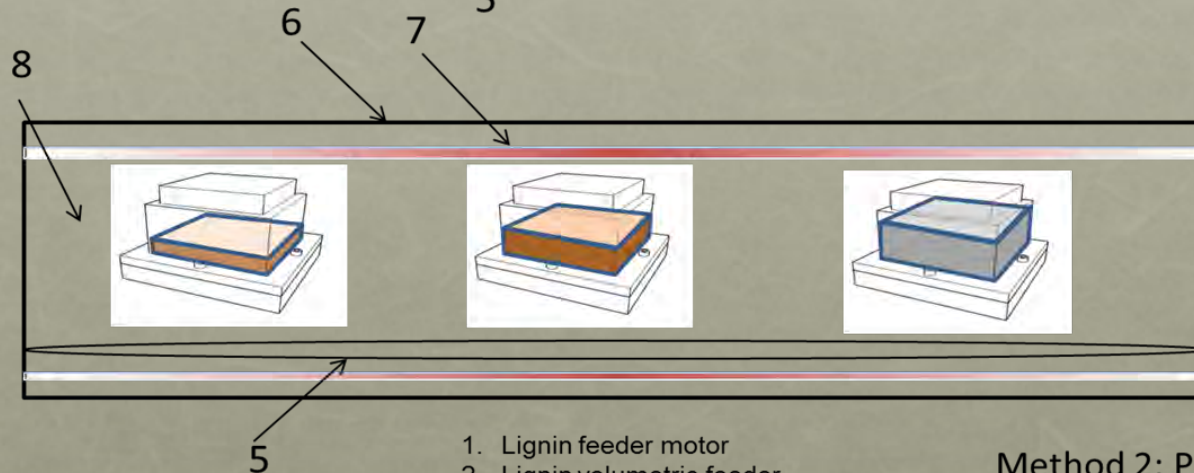
# Lignin Foam Process



# Lignin Foam Processes



Method 1: Extrusion process

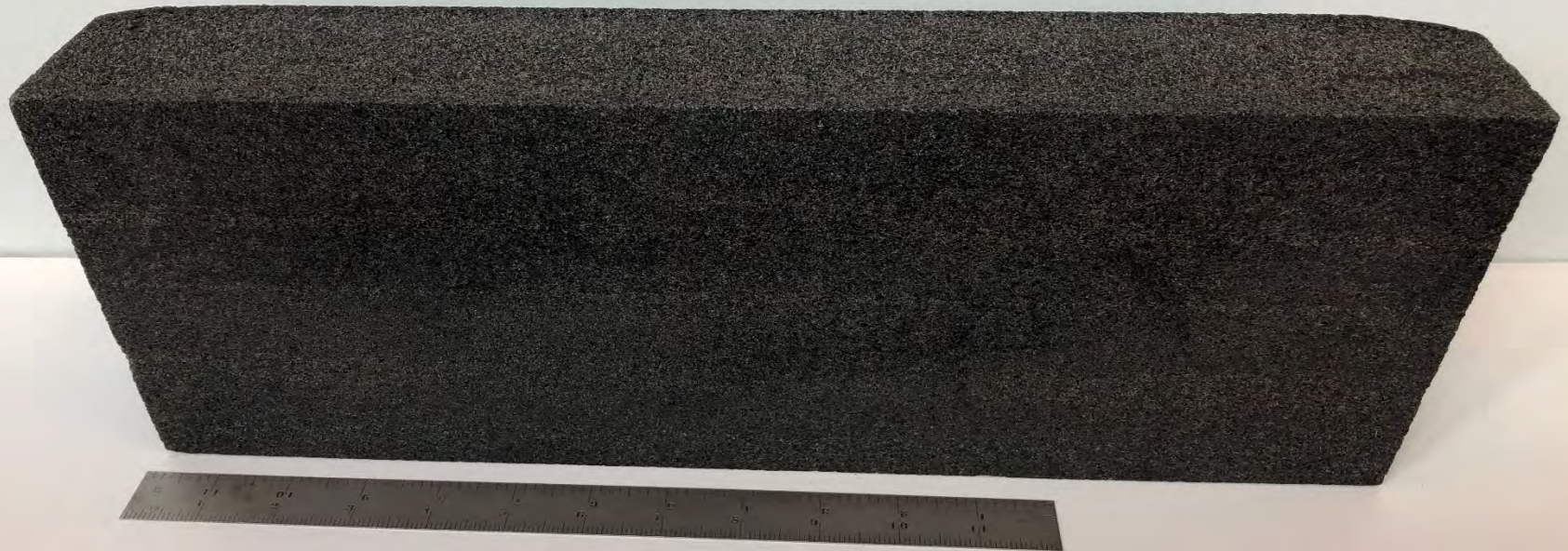


Method 2: Press mold process

1. Lignin feeder motor
2. Lignin volumetric feeder
3. Lignin feeder
4. Lignin heater (heat)
5. Conveyor belt
6. Heating vessel
7. Heating pan
8. Pressing mold



# Lignin Foam

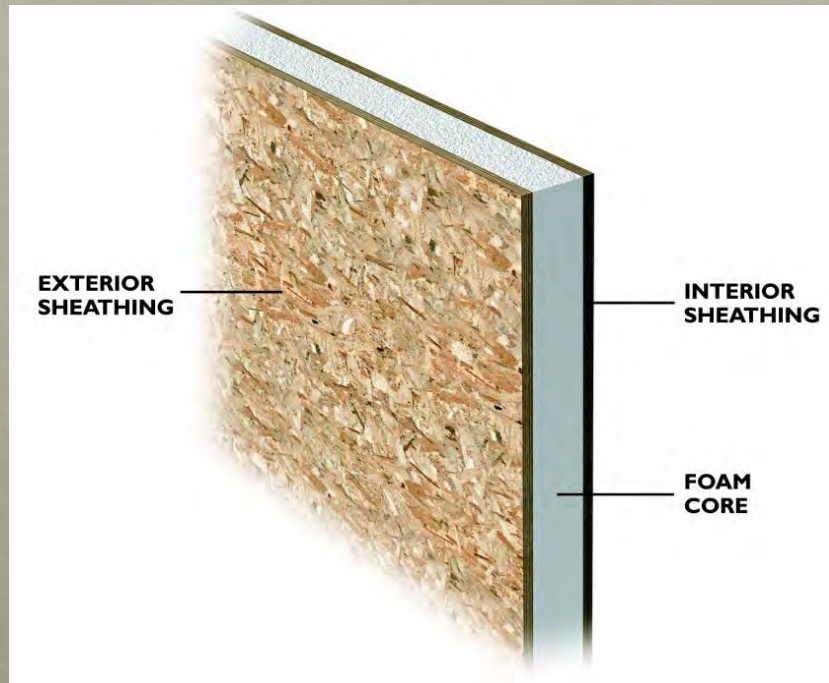


# Lignin Foam





# Structural Insolated Panel (SIP)





# Termite Test in FPL





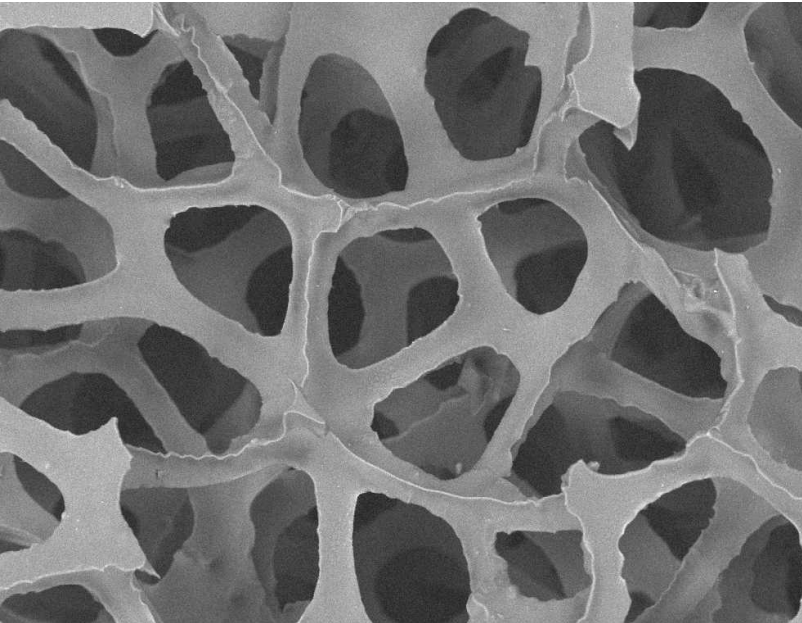
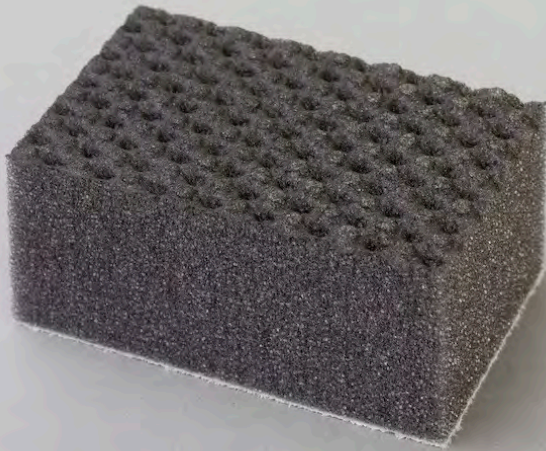
# Lignin Foam

Products	Polyurethane (PU) Foam	FPL Lignofoams
Precursors	Polyols, solvents, catalysts, blowing agents, surfactants, and crosslinking agents	Kraft lignin, thermoplastics
Lignin content (%)	-	70 - 92
Foam yield (wt%)	-	92 - 95
Density (g/cm3)	0.05-0.1	0.15-0.45
Porosity (%)	-	55-90
Compressive strength (MPa)	0.1-3	5-30
Thermal conductivity (W/m.K)	0.02-0.05	0.03-0.08
Termite test	-	Passed

# **Lignin-Based Carbon Foams**



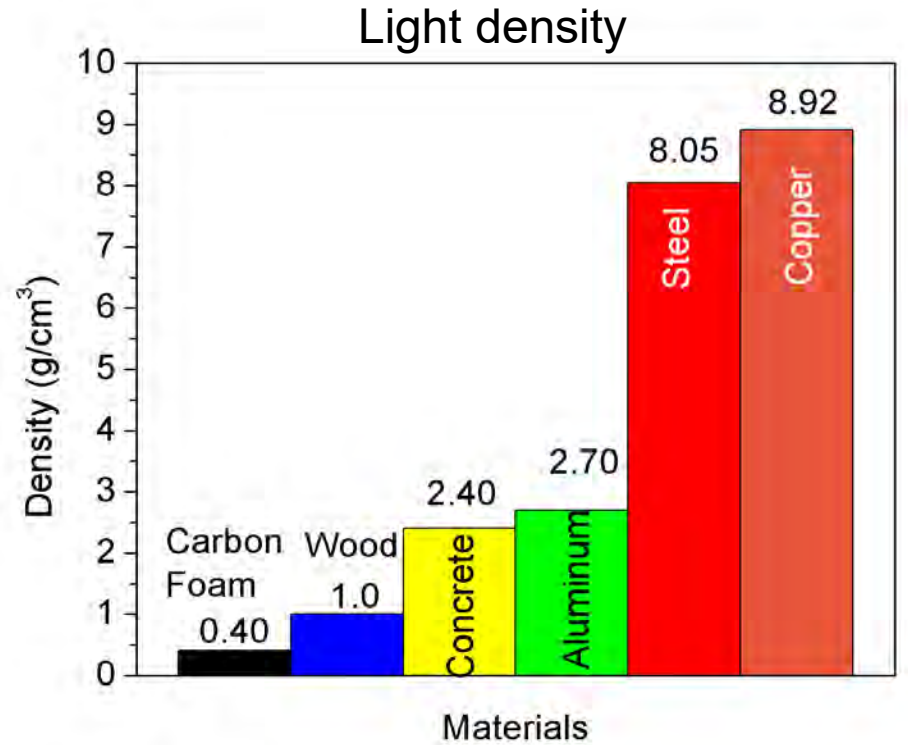
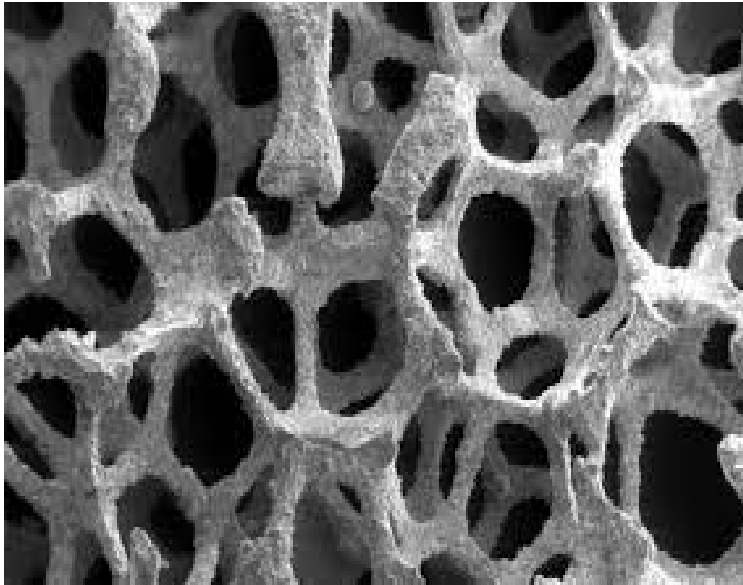
# What are Carbon Foams?



1. Porous carbon structures
2. Macropores
3. Open cells
4. Large surface area
5. Hydrophobic nature
6. Tailorable physical and electrical properties

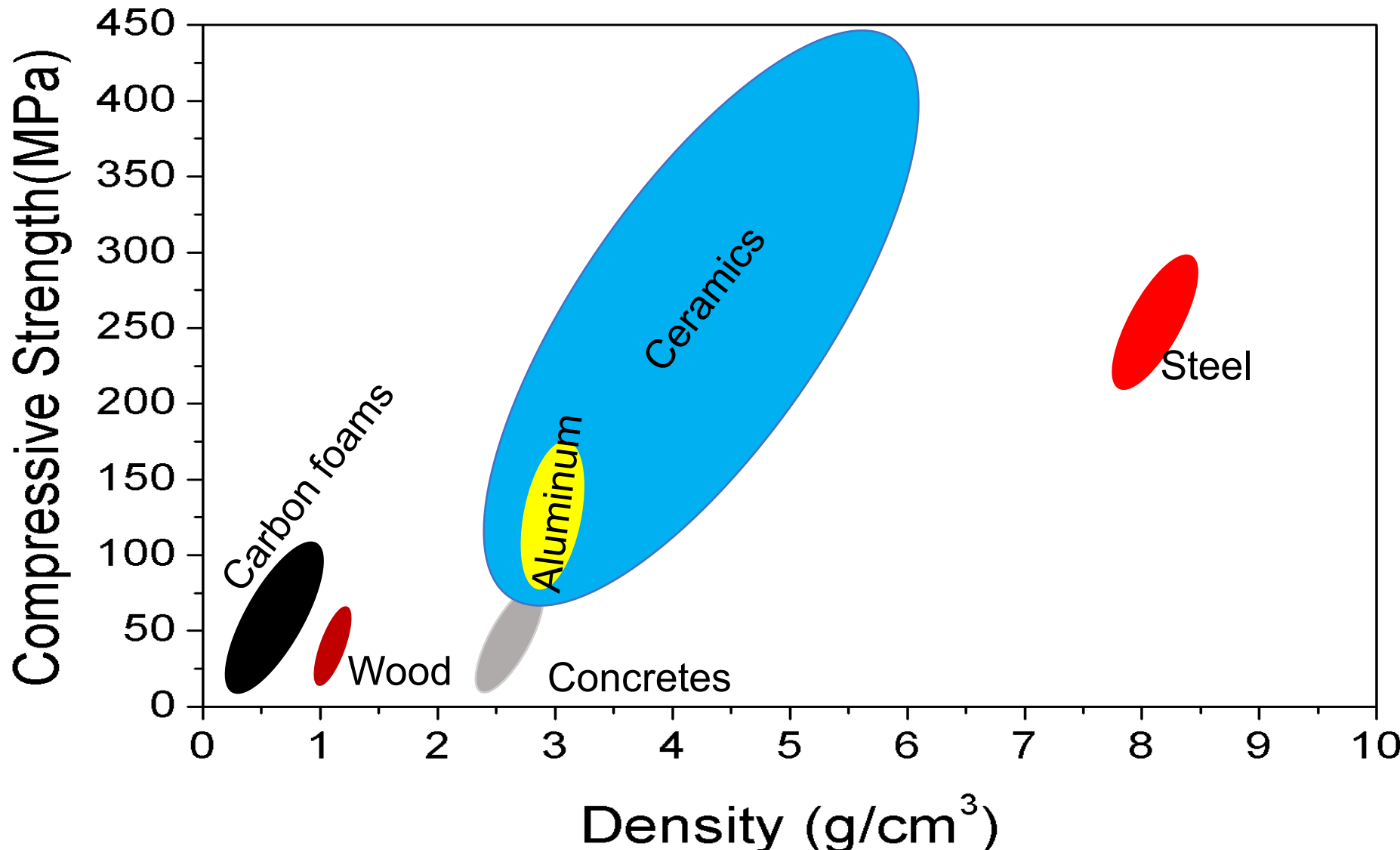
# Porous and Light

Porous, open cell carbon structure





# Compressive Strength



# Lignin-based Carbon Foam Process



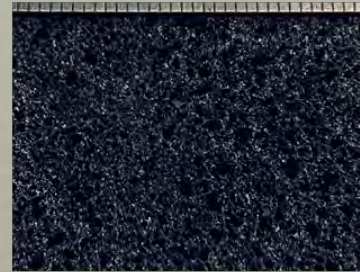
**Preparation  
of  
Ingredients**

Heat Kraft  
lignin at 100-  
450 °C in air



**Molding  
the lignin  
block**

Cold-press  
in mold



**Foaming of  
the lignin  
block**

300-500 °C in  
non-oxidizing  
atmosphere

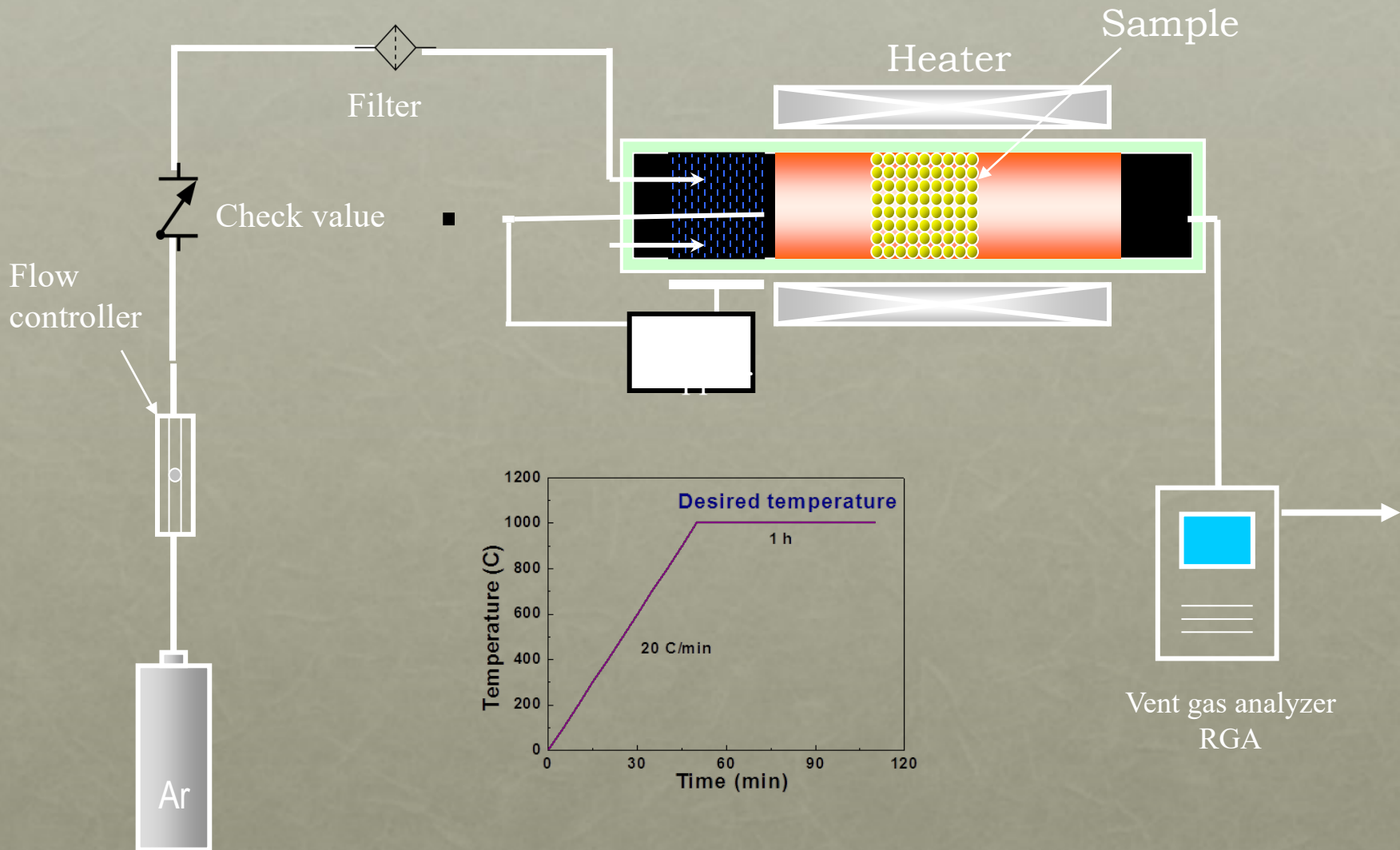


**Carbonization  
/graphitization  
of lignin foam**

700-1100 °C in  
non-oxidizing  
atmosphere

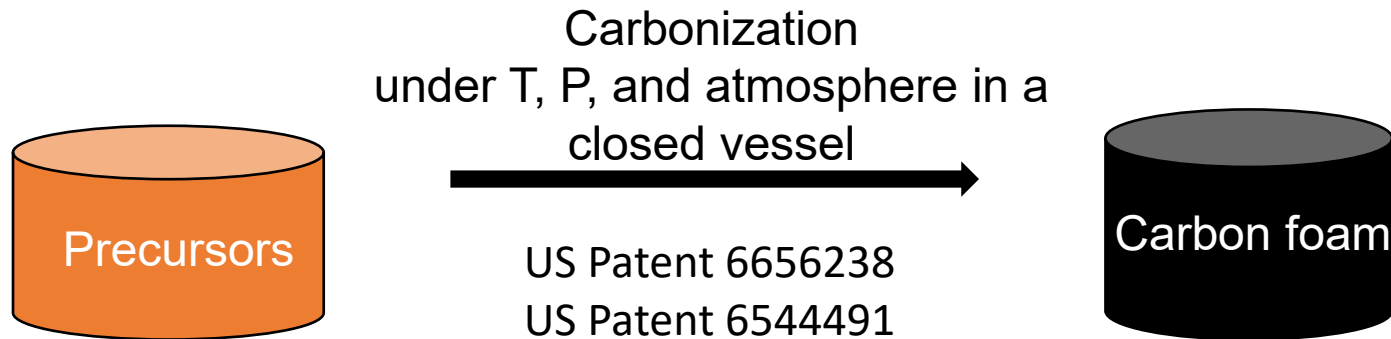


# Experimental Setup

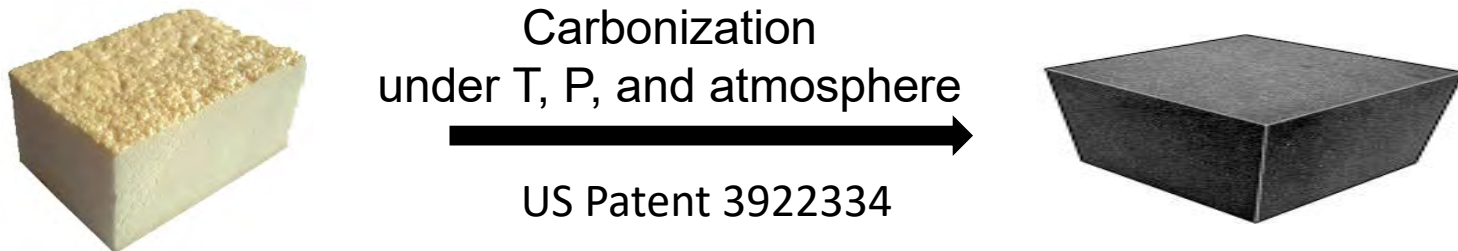


# Current Commercial Processes

## 1. Blowing of carbon precursors & carbonization



## 2. Template carbonization of carbon precursors



Impregnating PU foam with phenolic resin





# Lignin-Based Carbon Foam

## *Innovative FPL process:*

1. Bio-waste Kraft lignin

2. Flexible

- ❖ More recipes for pretreated Kraft lignin ingredients
- ❖ Different ingredients for different products

3. Cost effective

- ❖ Simple and safe process
- ❖ Molding in an open vessel
- ❖ Under atmospheric pressure



# Lignin-Based Carbon Foam

## Unique products:

1. Uniform porous products
2. Relative higher mechanical properties
3. Tailorable physical and electrical properties:  
*Density, porosity, mechanical performance, thermal conductivity, electrical conductivity, corrosion and fire resistant, high performance on EMI/RFI shielding, and hydrophilicity.*

# Lignin-Based Carbon Foams

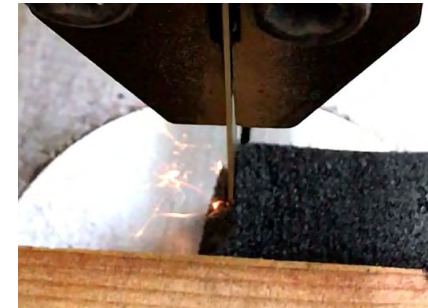




# Lignin-Based Carbon Foams



Metalized material



Fireproof



Strength



Penetrability

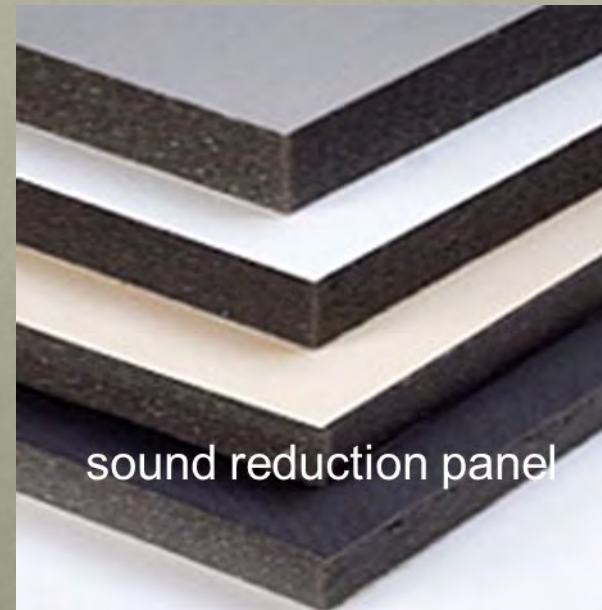


# Kraft Lignin Derived Carbon Foams

Manufactures	POCO	Koopers	CFOAM	USDA FPL
Brands	POCOFOAM	KFOAM	CFOAM	LCFOAM
Precursors	Pitch	Pitch	Pitch	Kraft Lignin
Density (g/cm3)	0.5	0.4-0.7	0.3-0.5	0.1-1.0
Porosity (%)	75	55-75		30-90
Compressive Strength (MPa)	3.0	1.5-3.5	5-22	10-100
Thermal Conductivity (W/m.K)	135 (out of plane) 45 (in plane)	140-240 (out of plane) 50 (in plane)	0.25-0.35	0.1-150
Electrical Resistivity (μΩ.m)		~30	20—2x10 <sup>9</sup>	5
Fire Resistant Temp. ( °C)	400	400	500	> 500

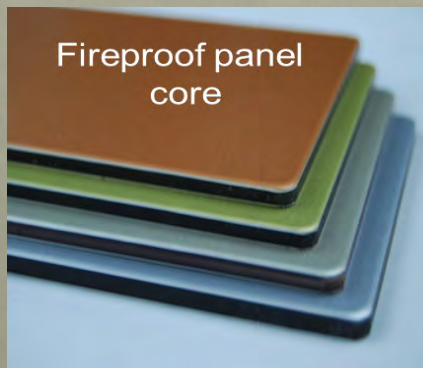
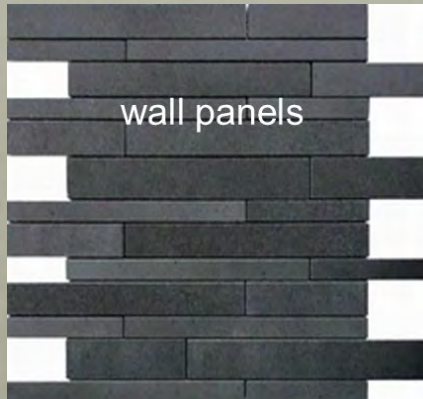
# Potential Applications

*Carbon Foam makes an excellent base material for all types of building construction due to its strength, thermal conducting, light weight and fire resistant properties*

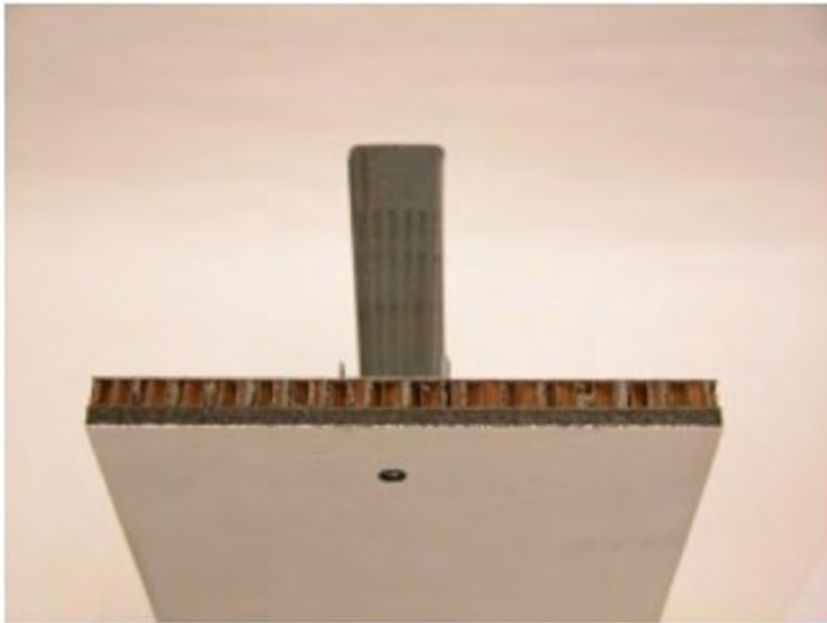




# Building Materials

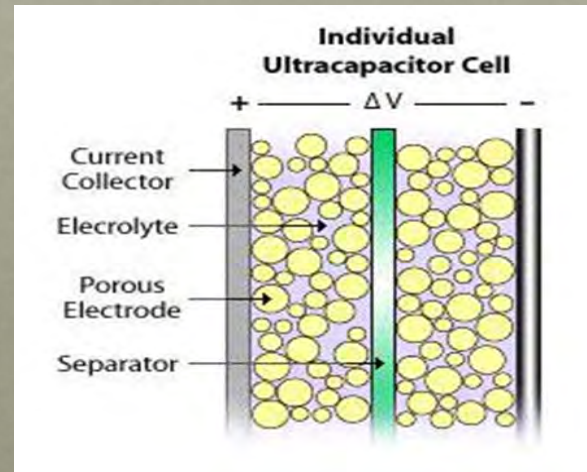
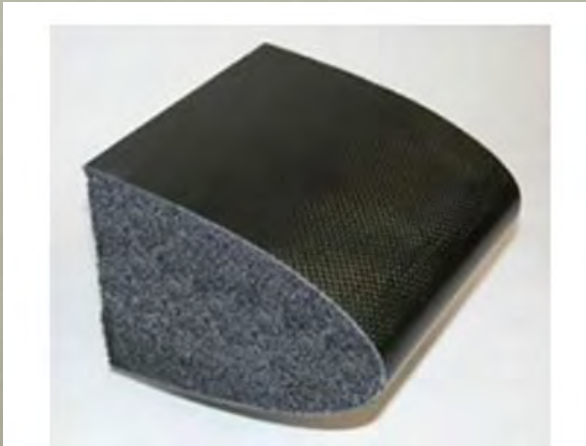


# Sandwich Structural Panels





# Other Potential Applications





# Other Potential Applications





# Summary and Future Plan

- ❖ Collaborated with Domtar since 2011 USDA/DOE BRDI project.
- ❖ Developed value-added intermediates from Kraft lignin.
- ❖ Potential high Value and high volume applications
  
- ❖ Pandemic Impact
  - ❖ Progress delayed
  - ❖ License terminated
  
- ❖ To develop a commercial mode and scale up production.
- ❖ To perform Life Cycle Analysis of lignin-based carbon materials

# Future Plan







Thank You!